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Herrig

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(54) **METHOD FOR DETERMINING CELLULAR RADIO CHANNEL ASSIGNMENTS TO MINIMIZE INTERFERENCE DUE TO INTERMODULATION PRODUCTS**

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(52) **U.S. Cl.** **455/62**; 455/450; 455/447
(58) **Field of Search** 455/447, 450, 455/62, 452, 464, 446, 448, 513, 509, 453, 501, 560, 561, 63, 422; 370/431, 57, 76, 118, 69.1

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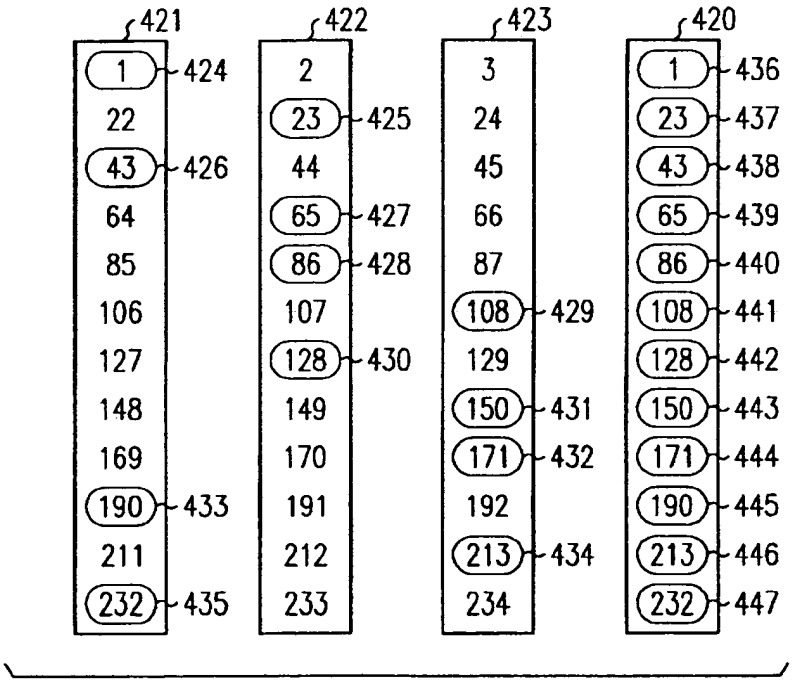
(57) **ABSTRACT**

A method is presented for reducing the frequency reuse factor by reducing the effects of intermodulation products in a cellular radio system. The cellular radio system constructs and stores modified channel sets that have a reduced measure of homogeneity. The cellular radio system selects a channel number from the appropriate modified channel set in order to support a call. This invention reduces radio interference, thus improving the quality of service and increasing the call capacity of the cellular radio system.

12 Claims, 9 Drawing Sheets



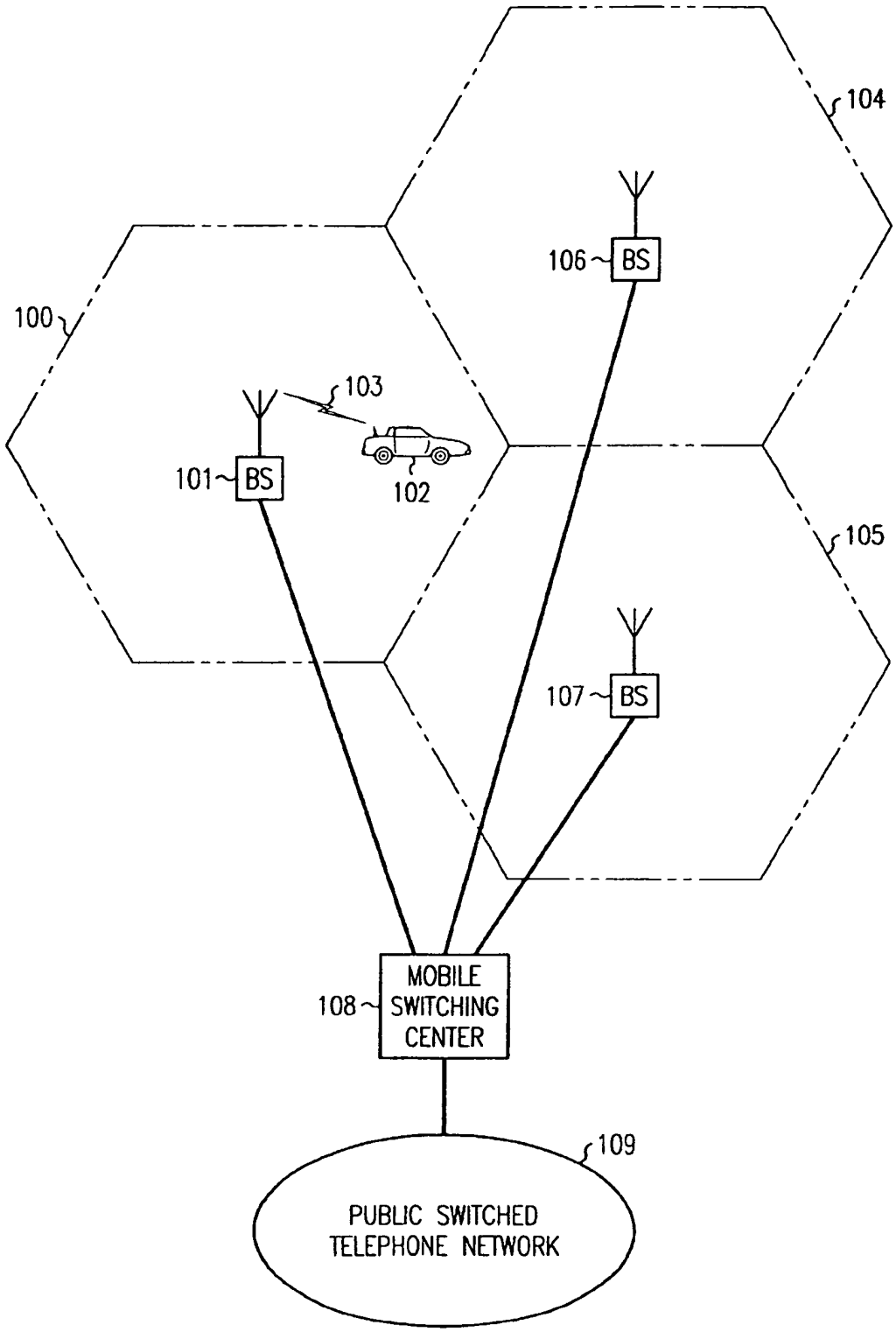

104
106
BS
100
103
101
BS
102
105
107
BS
MOBILE
SWITCHING
CENTER
108
109
PUBLIC SWITCHED
TELEPHONE NETWORK

FIG. 1

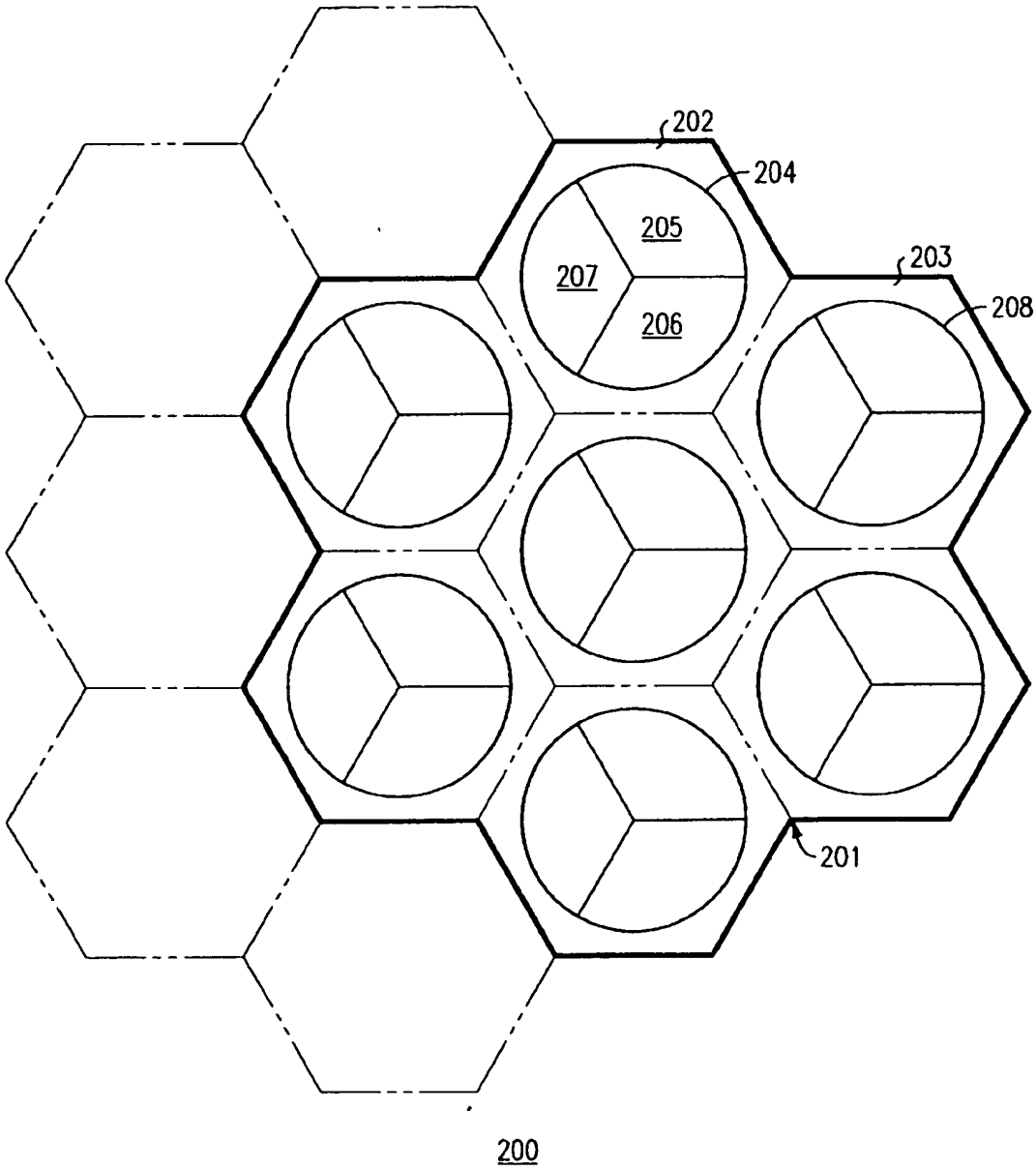
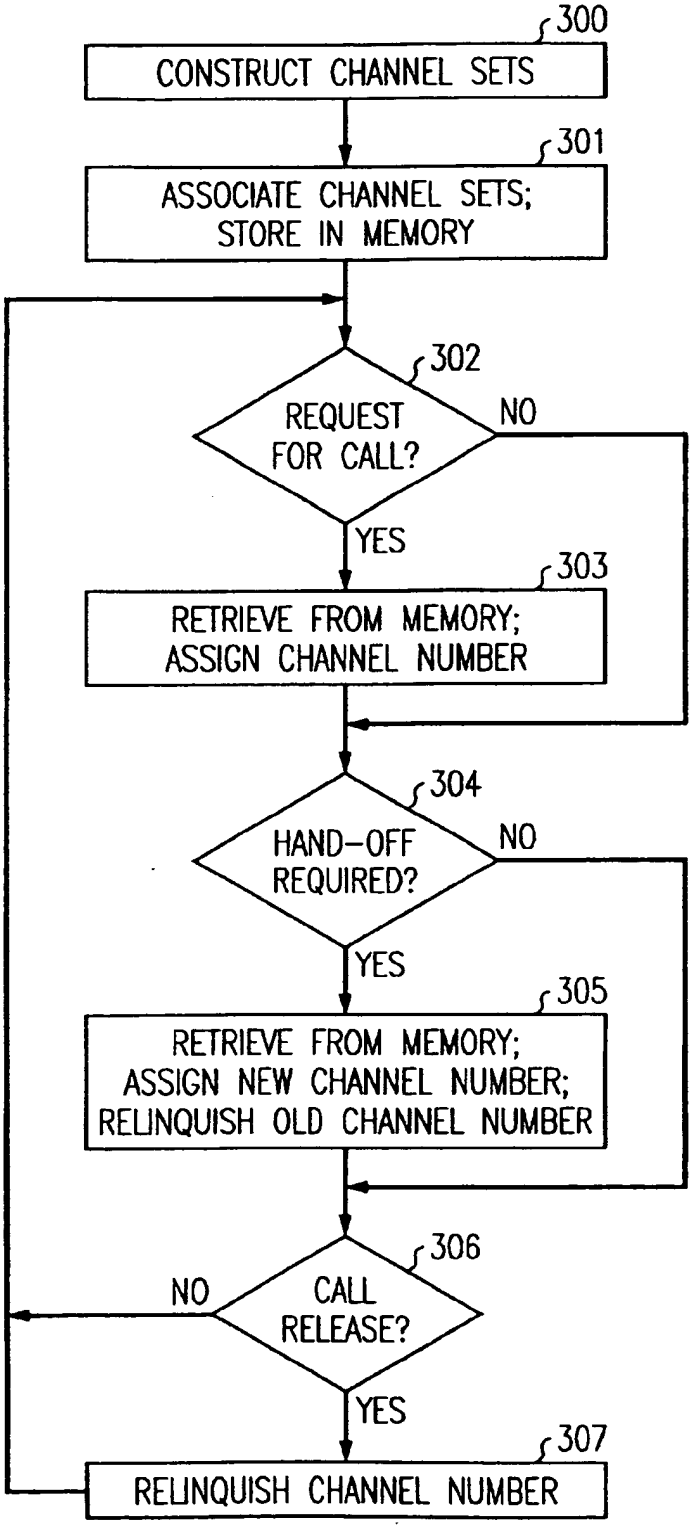


FIG. 2

FIG. 3A


300
CONSTRUCT CHANNEL SETS
301
ASSOCIATE CHANNEL SETS; STORE IN MEMORY
302
REQUEST FOR CALL?
NO
YES
303
RETRIEVE FROM MEMORY; ASSIGN CHANNEL NUMBER
304
HAND-OFF REQUIRED?
NO
YES
305
RETRIEVE FROM MEMORY; ASSIGN NEW CHANNEL NUMBER; RELINQUISH OLD CHANNEL NUMBER
306
CALL RELEASE?
NO
YES
307
RELINQUISH CHANNEL NUMBER

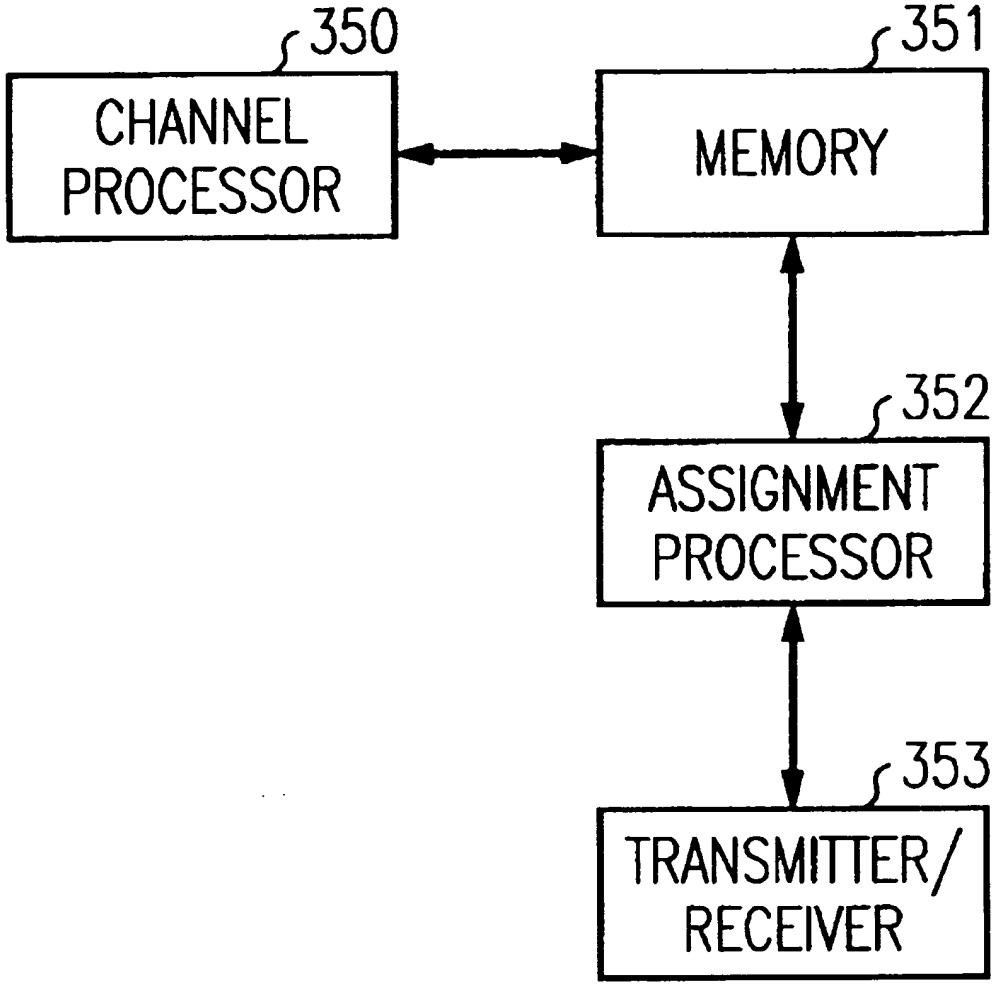
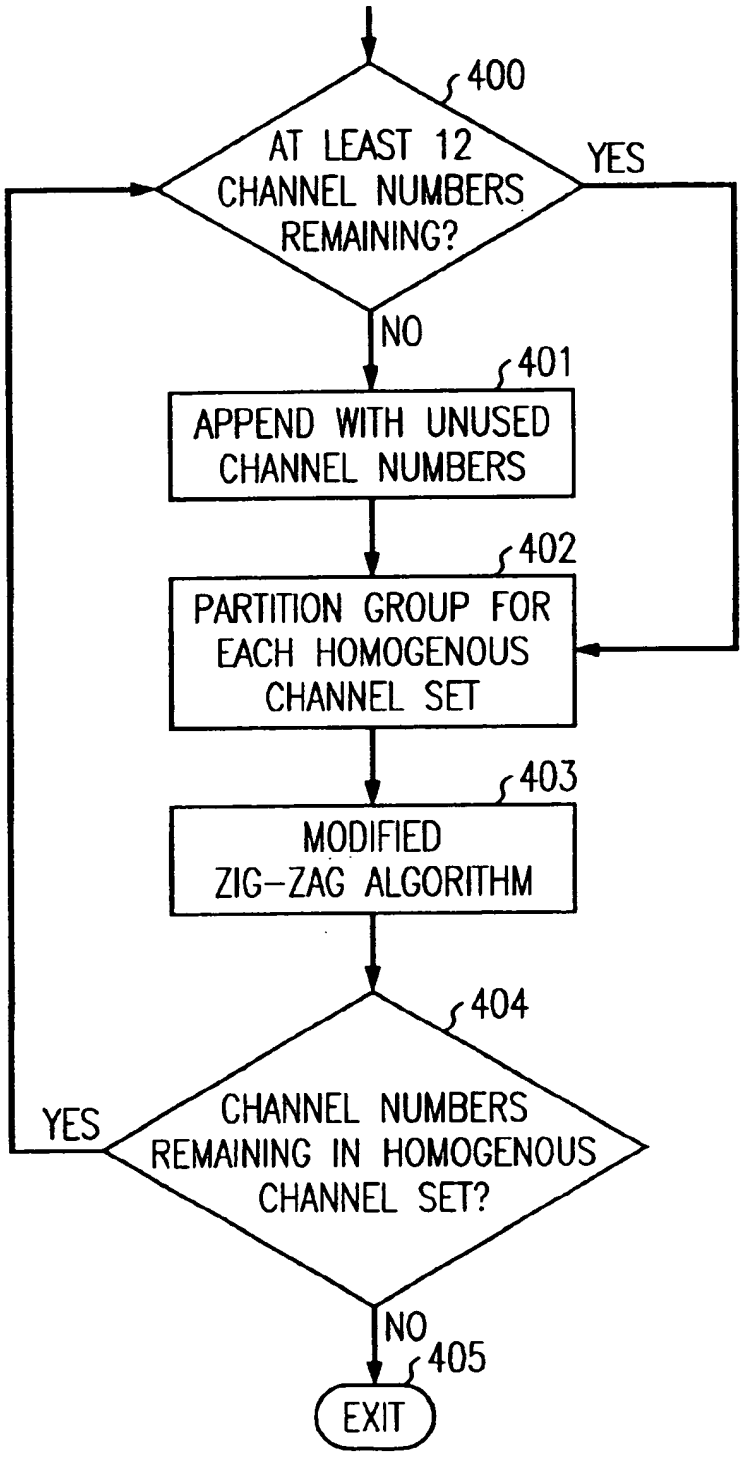

350
CHANNEL PROCESSOR
351
MEMORY
352
ASSIGNMENT PROCESSOR
353
TRANSMITTER/ RECEIVER

FIG. 3B

FIG. 4A


400
AT LEAST 12 CHANNEL NUMBERS REMAINING?
YES
NO
401
APPEND WITH UNUSED CHANNEL NUMBERS
402
PARTITION GROUP FOR EACH HOMOGENOUS CHANNEL SET
403
MODIFIED ZIG-ZAG ALGORITHM
404
CHANNEL NUMBERS REMAINING IN HOMOGENOUS CHANNEL SET?
YES
NO
405
EXIT

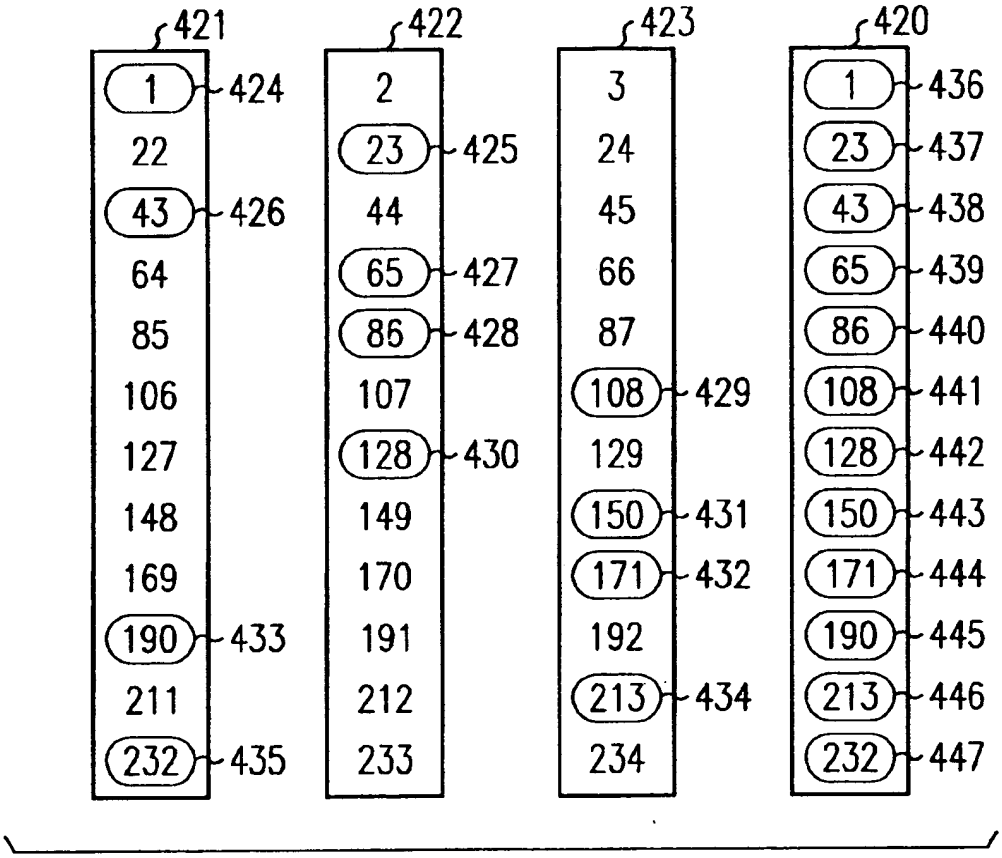

421
422
423
420
1
424
22
43
426
64
85
106
127
148
169
190
433
211
232
435
2
23
425
44
65
427
86
428
107
128
430
149
170
191
212
233
3
24
45
66
87
108
429
129
150
431
171
432
192
213
434
234
1
436
23
437
43
438
65
439
86
440
108
441
128
442
150
443
171
444
190
445
213
446
232
447

FIG. 4B

FIG. 4C

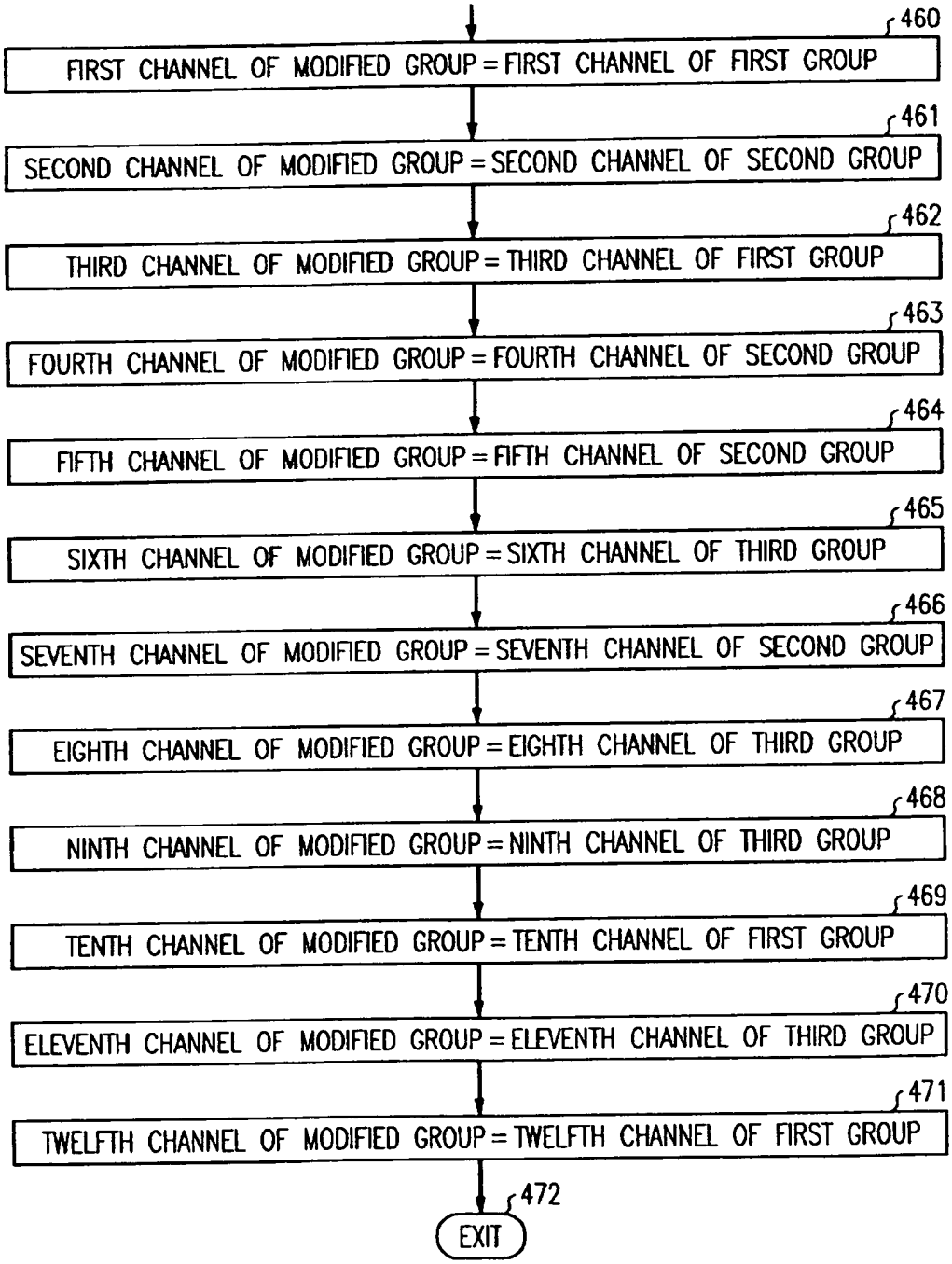

460
FIRST CHANNEL OF MODIFIED GROUP = FIRST CHANNEL OF FIRST GROUP
461
SECOND CHANNEL OF MODIFIED GROUP = SECOND CHANNEL OF SECOND GROUP
462
THIRD CHANNEL OF MODIFIED GROUP = THIRD CHANNEL OF FIRST GROUP
463
FOURTH CHANNEL OF MODIFIED GROUP = FOURTH CHANNEL OF SECOND GROUP
464
FIFTH CHANNEL OF MODIFIED GROUP = FIFTH CHANNEL OF SECOND GROUP
465
SIXTH CHANNEL OF MODIFIED GROUP = SIXTH CHANNEL OF THIRD GROUP
466
SEVENTH CHANNEL OF MODIFIED GROUP = SEVENTH CHANNEL OF SECOND GROUP
467
EIGHTH CHANNEL OF MODIFIED GROUP = EIGHTH CHANNEL OF THIRD GROUP
468
NINTH CHANNEL OF MODIFIED GROUP = NINTH CHANNEL OF THIRD GROUP
469
TENTH CHANNEL OF MODIFIED GROUP = TENTH CHANNEL OF FIRST GROUP
470
ELEVENTH CHANNEL OF MODIFIED GROUP = ELEVENTH CHANNEL OF THIRD GROUP
471
TWELFTH CHANNEL OF MODIFIED GROUP = TWELFTH CHANNEL OF FIRST GROUP
472
EXIT

FIG. 5

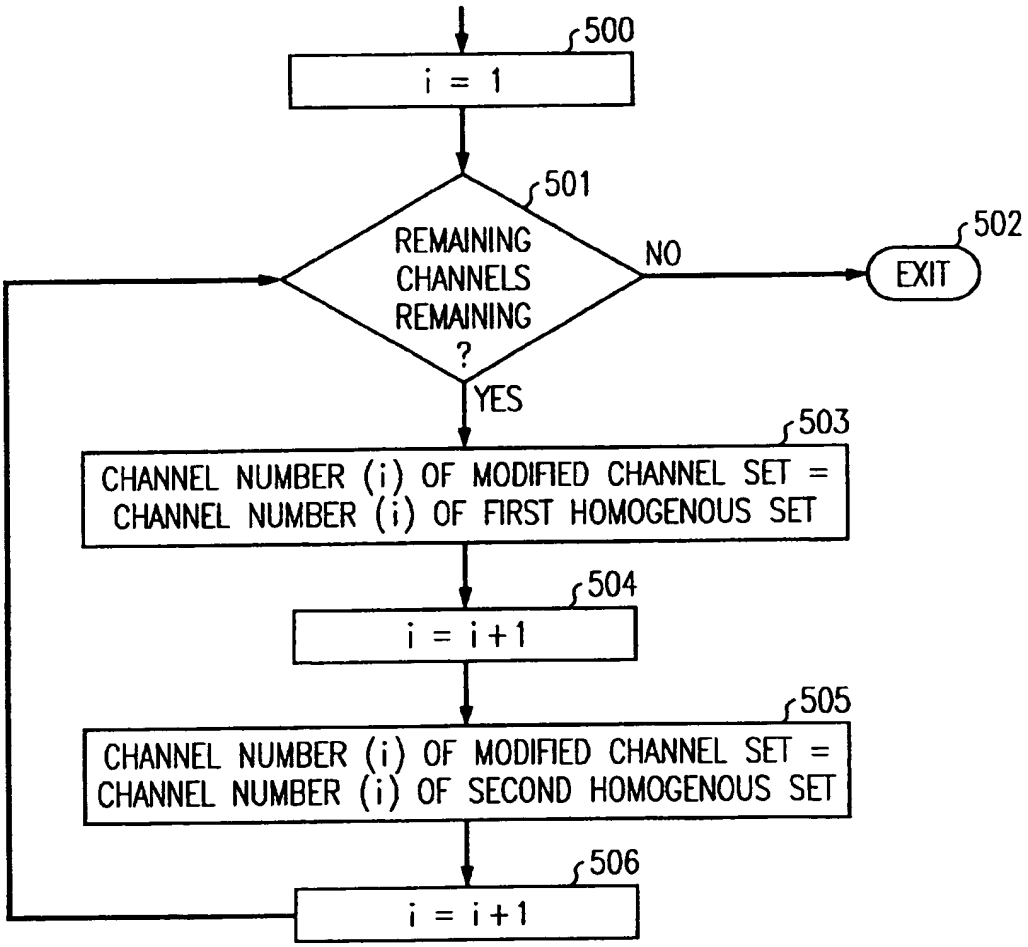
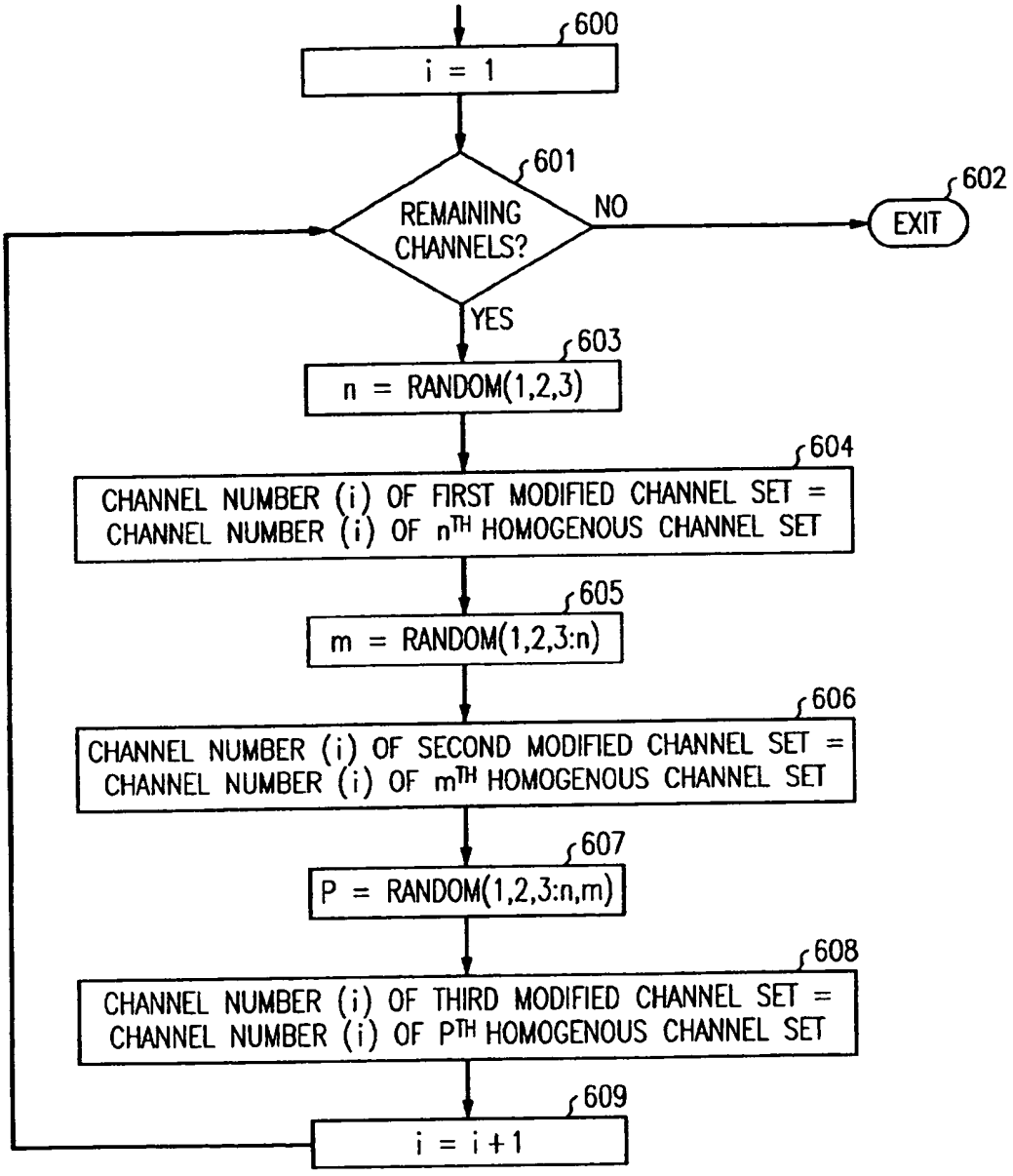

500
i = 1
501
REMAINING CHANNELS REMAINING ?
NO
502
EXIT
YES
503
CHANNEL NUMBER (i) OF MODIFIED CHANNEL SET = CHANNEL NUMBER (i) OF FIRST HOMOGENOUS SET
504
i = i+1
505
CHANNEL NUMBER (i) OF MODIFIED CHANNEL SET = CHANNEL NUMBER (i) OF SECOND HOMOGENOUS SET
506
i = i+1

FIG. 6


600
i = 1
601
REMAINING CHANNELS?
NO
602
EXIT
YES
603
n = RANDOM(1,2,3)
604
CHANNEL NUMBER (i) OF FIRST MODIFIED CHANNEL SET = CHANNEL NUMBER (i) OF nTH HOMOGENOUS CHANNEL SET
605
m = RANDOM(1,2,3:n)
606
CHANNEL NUMBER (i) OF SECOND MODIFIED CHANNEL SET = CHANNEL NUMBER (i) OF mTH HOMOGENOUS CHANNEL SET
607
P = RANDOM(1,2,3:n,m)
608
CHANNEL NUMBER (i) OF THIRD MODIFIED CHANNEL SET = CHANNEL NUMBER (i) OF PTH HOMOGENOUS CHANNEL SET
609
i = i+1

METHOD FOR DETERMINING CELLULAR RADIO CHANNEL ASSIGNMENTS TO MINIMIZE INTERFERENCE DUE TO INTERMODULATION PRODUCTS

FIELD OF THE INVENTION

This invention relates to reducing the frequency reuse factor in a cellular radio system. In particular, intermodulation interference is reduced by choosing channel numbers with a given channel set.

BACKGROUND OF THE INVENTION

Cellular radio service is expanding at an explosive rate and will be ubiquitous in the near future. Thus, it is important that the radio spectrum be used to provide service for more customers with little or no extra cost to the service provider. In cellular radio service, a predetermined radio frequency spectrum is allocated to carry the communication between a user's cellular telephone and the service provider's base station (the gateway into the cellular switching network.) The spectrum is divided into frequency channels, commonly referred to as "channel numbers," and are reused by base stations within a service provider's area. The greater the reuse of frequency channels, the greater the number of cellular radio subscribers that can be simultaneously served. However, one frequency channel cannot be used by two adjacent base stations because each will interfere with one another. While reusing frequency channels more often increases the frequency spectrum efficiency, it also increases the resulting interference. Thus, one skilled in the art balances each factor against the other in order to achieve a compromise.

Radio technology has long recognized the problem of intermodulation (IM) products in radio communications systems (including cellular radio systems). The mixing of two sinusoidal signals having different frequencies in a nonlinear system generates IM products that may interfere with other frequency channels, thus degrading signal quality. IM products correspond to the sum and difference frequency components that are attributed to the "heterodyning process." The heterodyning process is discussed in Carson, Ralph S., *Radio Communications Concepts*, John Wiley and Sons, 1990, pp. 94–99. Heterodyning does not occur in a completely linear system because no new frequency components can be created. A linear system is a system that has the property of superposition. Superposition means that the output signal of the system resulting from a plurality of input signals can be determined by adding the individual output signals corresponding to each of the plurality of input signals. If the system is not completely linear, new frequency components are created whenever two or more original frequency components exist.

To illustrate the hetrodyning problem, assume that the original frequency components are f.sub.1 and f.sub.2. Third-order nonlinear characteristics generate third-order IM products having frequency components of 2f.sub.1–f.sub.2, 2.sub.2–f.sub.1, f.sub.1+2f.sub.2, 2f sub.1+f.sub.2, 3f.sub.1, and 3f.sub.2. The IM products corresponding to differences are of greater concern because these are more difficult to filter than those corresponding to sums. As an example, let f.sub.1 equal 871.920 MHz and f.sub.2 equal 872.550 MHz. Third-order IM products corresponding to differences are generated at 871.290 MHz (2f.sub.1–f.sub.2) and at 873.180 MHz (2f.sub.2–f sub.1). Third-order IM products corresponding to sums are generated at 2617.020 MHz (f.sub.1+2f.sub.2), 2616.390 MHz (2f.sub.1+f.sub.2), 2615.760 MHz (3f.sub.1), and 2617.650 MHz (3f.sub.2). Higher-order nonlinear characteristics generate higher-order IM products such as the fifth-order and seventh-order IM products. The nth-order IM products have frequency components of pf.sub.1–qf.sub.2 and pf.sub.2–qf.sub.1, where p+q equals n and p is greater than q. Higher-order IM products have a lesser effect than the third-order IM products because the corresponding signal levels have less amplitude. Even-order IM products are generally ignored because the corresponding frequency components can be filtered. (In the above example, the second-order IM product has a frequency component of f.sub.1+f.sub.2, which equals 1744.470 MHz. This frequency is sufficiently removed from the spectrum centered around 850 MHz and thus can be easily filtered.) Third-order IM products are typically responsible for the most adverse effects on other IM products.

The discussion heretofore specified only two frequency components. If more than two frequency components exist, then each possible pair of all frequency components (channel numbers) must be considered, where the collection of channel numbers is commonly called a "channel set" in the art of cellular radio. If the frequency of an IM product is coincident with a channel number of the channel set, then a "hit" occurs. The total effect is determined by adding the individual effects of each pair. For example, the case in which each of two frequency pairs generate a hit on a given frequency will result in more severe effects than the case in which only one frequency pair generates a hit at the given frequency. Moreover, third-order IM products are also generated by the mixing of three signal components (triplets) having frequencies of f.sub.1, f.sub.2, and f.sub.3, respectively. In such cases, third-order IM products having frequency components of –f.sub.1+f.sub.2+f.sub.3, f.sub.1–f.sub.2+f.sub.3, and f.sub.1+f.sub.2–f.sub.3 are the dominant components. Thus, the total effect of third-order IM products is exacerbated by the presence of these components. The subsequent quantitative assessment of third-order IM products includes only the effects of frequency pairs and not frequency triplets.

In a cellular radio system, full duplex operation is supported so that communication from the serving base station to the mobile subscriber unit (commonly associated with the downlink) and from the mobile subscriber unit to the base station (commonly associated with the uplink) can occur concurrently. The frequency of the downlink (base station to mobile subscriber unit) is spaced 45 MHz from the frequency of the uplink (mobile subscriber unit to base station). For a given call, the serving base station allocates a transmitter and a receiver. Similarly, the mobile subscriber unit tunes its transmitter and receiver to the frequencies associated with the allocated base station equipment. A channel number is associated with both a transmitting frequency and a receiving frequency. For example, the channel number 22 in the B band of the AMPS spectrum is 870.660 MHz for the base station's transmit frequency (downlink) and is 825.660 MHz for the base station's receive frequency (uplink). These frequency assignments are the mobile subscriber unit's receive frequency (downlink) and transmit frequency (uplink), respectively.

IM products are generated if nonlinear characteristics exist at the transmitter, receiver, or structures between the mobile subscriber unit and base station. At the base station, multiple transmitted signals, each having a corresponding frequency value, are combined by an RF combiner or power amplifier so that a common antenna can be utilized. Any

nonlinear characteristics of the RF combiner, power amplifier, couplers, filters, duplexers, and cables will also cause signals corresponding to IM products to be transmitted by the antenna. These IM products are detrimental to a call if the frequency of one or more of the IM products is the same as a frequency associated with the call. Even if the RF combiner or power amplifier were completely linear, the receiver of the mobile subscriber unit is exposed to multiple signals having different frequencies. One of the signals corresponds to the frequency associated with the call while the other signals are associated with interference (i.e. calls intended for other mobile subscriber units). If the receiver of the mobile subscriber unit has nonlinear characteristics, IM products are generated. The nonlinear characteristics of the receiver are reflected in the third-order intercept point of the receiver. (Carson, Ralph S., *Radio Communications Concepts*, John Wiley and Sons, 1990, 94–99.)

Furthermore, the generation of IM products can be associated with factors external to the base station and mobile subscriber unit. In fact, any nonlinear junction or device encountered by a signal in its path of propagation can generate IM products. (Boucher, Neil J., *The Cellular Radio Handbook*, Quantum Publishing, 1995, p. 100.) Typical nonlinear junctions or devices include bolted tower joints, antenna clamps, tower guy wires, metal fences, chains, and light bulbs. Such factors may be very difficult to identify and to eliminate.

The discussion heretofore addresses the generation of IM products for the downlink (base station to mobile subscriber unit). However, an analogous discussion can be presented for the uplink (mobile subscriber unit to base station). IM products are detected at the base station's receiver if nonlinear characteristics exist somewhere in the uplink path or at the base station's receiver and if a plurality of mobile subscriber units are simultaneously transmitting at different frequencies. Signals associated with these different frequencies can mix at points having nonlinear characteristics to generate IM products.

There are several known approaches to diminish the effects of IM products in a radio system. The first approach is to reduce the nonlinear characteristics of the electronic components such as RF power devices. However, this approach may not be technically possible or economically feasible. A second approach is to cancel IM products by inducing a signal that is inverted with respect to the distortions caused by the nonlinear characteristics of the electronic circuitry. Such an approach is suggested by U.S. Pat. No. 5,606,286 that issued to Burns. This approach requires additional complexity in electronic circuitry. The third approach is to utilize only frequencies, which reduce the occurrences of IM products by a frequency planning procedure. U.S. Pat. No. 5,295,138, issued to Greenberg, et al., and assigned to Northwest Starcon Limited Partnership uses this approach. The '138 patent reduces the effects of IM products within a common communication channel bandwidth by determining carrier frequencies, which are contained in this bandwidth, so that the IM products are reduced. The '138 patent adjusts carrier frequencies, performs measurements of the resulting IM products, and readjusts the carrier frequencies based upon the measurement results. The '138 patent addresses a problem encountered in satellite radio systems in which the assigned frequencies are randomly selected and moved in an iterative process to reduce the effects of IM products. This approach, however, does not address situations in which frequencies are reused as with cellular radio systems.

Moreover, current literature in the field of cellular radio leads away from the present invention. For example, one reference states that the effects of IM products "will not affect channels within the transmitted band design" when considering the RF combiner with respect to the relatively low amplitudes of the IM products that are generated. (Lee, William C. Y., *Mobile Cellular Telecommunications Systems*, McGraw-Hill Book Company, 1989, pp. 231–232.)

Even though interference in a cellular radio system is a well-recognized problem (any increase of interference will degrade the call capacity of the cellular radio system), the sources of this interference may not be well defined. The current art of cellular radio recognizes co-channel and adjacent channel interference as being two sources of interference. Both co-channel and adjacent interference are addressed by the frequency planning practice detailed in a number of references, e.g. Boucher, Neil, J., *The Cellular Radio Handbook*, Quantum Publishing, 1995, pp. 116–118. The current state of the art propounds that regularly spaced channel sets, each channel set containing a plurality of channel numbers, be assigned in a repeated fashion to cell sites within the coverage area of the cellular radio system. This approach to frequency planning for a cellular radio system fails to recognize the effects of IM products as a source of interference. Reducing the interference attributable to IM products reduces the total interference experienced at the mobile subscriber unit and at the base station.

SUMMARY OF THE INVENTION

The problem of reducing the frequency reuse factor by reducing the effects of intermodulation (IM) products in a cellular radio system is solved and a technical advance is achieved. The invention consists of determining a channel set for each antenna sector of each base station and of assigning an appropriate channel number of the channel set to the associated base station equipment and mobile subscriber unit in order to support a cellular call. Channels are chosen so that the measure of homogeneity is reduced, thus reducing interference associated with IM products. Consequently, the total interference is reduced, allowing for a smaller reuse frequency factor and enhancing the call capacity of the cellular radio system. If the call requires a handoff from the serving base station to another base station or from one antenna sector to another antenna sector of the serving base station, the cellular radio system assigns another channel number, as determined by the invention, so that the call can continue by being served by the second base station or by the second antenna sector.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a cellular radio system supporting a mobile subscriber unit during a call as supported by prior art;

FIG. 2 illustrates a cell cluster for a cellular radio system having a three-sector antenna configuration and a reuse factor of seven as supported by prior art;

FIG. 3*a* is a flow diagram showing the logic for implementing the invention;

FIG. 3*b* is a block diagram illustrating an apparatus embodiment in accordance with the present invention;

FIG. 4*a* illustrates partitioning channel sets into groups so that the modified zig-zag algorithm can be applied;

FIG. 4*b* illustrates an example of applying the modified zig-zag algorithm in order to construct a channel set that reduces IM products;

FIG. 4*c* shows a flow diagram for the modified zig-zag algorithm;

FIG. 5 illustrates a flow diagram of the zig-zag algorithm in order to construct a channel set that reduces IM products; and

FIG. 6 illustrates a flow diagram of the randomized algorithm in order to construct a channel set that reduces IM products.

DETAILED DESCRIPTION

FIG. 1 illustrates a cellular radio system supporting a mobile subscriber unit **102** during a call. Mobile subscriber unit **102** is located within cell **100** and is served by base station **101**. Base station **101** is approximately located at the center of cell **100**. Base station **101** communicates with mobile subscriber unit **102** over a radio channel **103**, associated with the base station's transmit frequency (mobile station unit's receive frequency) and with the mobile subscriber unit's transmit frequency (base station's receive frequency). Mobile subscriber unit **102** may move outside cell **100** to either cell **104** or cell **105**. In such a case, mobile subscriber unit **102** will be served by base station **106** or base station **107**, respectively. Base stations **101**, **106**, and **107** are controlled by mobile switching center **108**. In addition, mobile switching center provides a telephony connection between base stations **101**, **106**, and **107** in order to complete calls between mobile subscriber unit **102** and public switching telephone network (PSTN) **109**.

FIG. 2 illustrates a cell cluster **201** within a cellular radio system **200** having a three-sector antenna configuration and a frequency reuse factor of seven. The service area of cellular radio system **200** is partitioned into cells such as cell **202** and cell **203**. Cell **202** is served by base station **204**, and cell **203** is served by base station **208**. Cell **202** is configured with three antenna sectors: alpha antenna sector **205**, beta antenna sector **206**, and gamma antenna sector **207**. Each cell cluster consists of seven cells in such a configuration. Because the frequency reuse factor is seven, the frequency spectrum is reused by every cell cluster **201**. Each cell requires three channel sets; therefore, a total of twenty-one channel sets are required by cell cluster **201**. Other frequency reuse factors can be employed, but a frequency reuse factor is typically seven for a three-sector antenna configuration. For an omnidirectional configuration, a frequency reuse factor of thirteen is typical. In such a configuration, the radio spectrum is repeated every thirteen cells. Because each cell requires one channel set, a total of thirteen channel sets are required by a cell cluster. The cell clusters, or a portion thereof, are repeatedly deployed in order to expand cellular coverage as needed.

The usable frequency spectrum is partitioned into channel sets. Each channel set contains a plurality of channel numbers, each channel number corresponds to both a transmit frequency and a receive frequency. Tables 1, 2, and 3 illustrate an example of the partitioning of a 850 MHz cellular frequency spectrum into channel sets for the A band (limited spectrum). (Boucher, Neil, J., *The Cellular Radio Handbook*, Quantum Publishing, 1995, p. 117.) The frequency assignments, as shown in Tables 1, 2, and 3, are followed in current practice.

TABLE 1

Purely Homogeneous Frequency Sets for Alpha Sector

Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
1	2	3	4	5	6	7
22	23	24	25	26	27	28
43	44	45	46	47	48	49
64	65	66	67	68	69	70
85	86	87	88	89	90	91

TABLE 1-continued

Purely Homogeneous Frequency Sets for Alpha Sector

Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
106	107	108	109	110	111	112
127	128	129	130	131	132	133
148	149	150	151	152	153	154
169	170	171	172	173	174	175
190	191	192	193	194	195	196
211	212	213	214	215	216	217
232	233	234	235	236	237	238
253	254	255	256	257	258	259
274	275	276	277	278	279	280

TABLE 2

Purely Homogeneous Frequency Sets for Beta Sector

Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
8	9	10	11	12	13	14
29	30	31	32	33	34	35
50	51	52	53	54	55	56
71	72	73	74	75	76	77
92	93	94	95	96	97	98
113	114	115	116	117	118	119
134	135	136	137	138	139	140
155	156	157	158	159	160	161
176	177	178	179	180	181	182
197	198	199	200	201	202	203
218	219	220	221	222	223	224
239	240	241	242	243	244	245
260	261	262	263	264	265	266
281	282	283	284	285	286	287

TABLE 3

Purely Homogeneous Frequency Sets for Gamma Sector

Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
15	16	17	18	19	20	21
36	37	38	39	40	41	42
57	58	59	60	61	62	63
78	79	80	81	82	83	84
99	100	101	102	103	104	105
120	121	122	123	124	125	126
141	142	143	144	145	146	147
162	163	164	165	165	166	167
183	184	185	186	187	188	189
204	205	206	207	208	209	210
225	226	227	228	229	230	231
246	247	248	249	250	251	252
267	268	269	270	271	272	273
288	289	290	291	292	293	294

Tables 1, 2 and 3 illustrate channel sets that are assigned to each cell in a cell corresponding to the alpha, beta, and gamma sectors, respectively for a three-sector antenna configuration and a frequency reuse factor of seven. Each of the channel sets in Tables 1, 2, and 3 has a uniform frequency separation equal to 21 (which is equivalant to 21*30 KHz or 630 KHz) between each adjacent channel numbers within a channel set. Each channel set has a uniform distribution in that each adjacent channel number is separated by 21 or multiples of 21. Each channel such set is referred as a "purely homogeneous channel set." In the context of this discussion, a channel set having this uniform property is referred as a "purely homogeneous channel set" because every entry in the channel set is separated by 21 or multiples of 21. Moreover, several purely homogeneous channel sets

can be combined to form another channel set. As an example, consider the B frequency band of the 850 MHz cellular spectrum. The B frequency band is further partitioned into the basic B band (880 MHz to 890 MHz for the base station's transmit frequency and 835 MHz to 845 MHz for the base station's receive frequency) and the B' band (891.5 MHz to 894 MHz for the base station's transmit frequency and 846.5 MHz to 849 MHz for the base station's receive frequency), each of which corresponds to a purely homogeneous subset.

Channels in a homogeneous channel set generates IM products that fall on other channels in the channel set. As known in the art, in each purely homogeneous channel set of Tables 1, 2, and 3 each channel number experiences at least 6 occurrences ("hits") of third-order IM products (of the form 2f.sub.1−f.sub.2) having the same frequency. As an example, there are 6 hits corresponding to channel number 22 in the first channel set of Table 1 (i.e. 2*43–64, 2*64–106, 2*85–148, 2*106–190, 2*127–232, and 2*148–274). Each hit corresponds to an IM product having an associated transmit frequency and receive frequency. Also, other third-order IM products, such as those attributable to frequency triplets, and higher-order IM products are generated. Each occurrence of an IM product produces interference to a given channel number, thus degrading the quality of communication between the base station and mobile subscriber unit. The frequency reuse factor is important in determining the call capacity of a cellular radio system. For an omindirectional configuration, the size of the channel set associated with a cell is equal to the total number of channel numbers available to the entire cellular system divided by the frequency reuse factor. For a directional configuration, the channel sets associated with the antenna sectors of a cell are determined by equally dividing the channel set that would have been assigned to the cell for an omnidirectional configuration.

The frequency reuse factor is chosen in order to achieve a desired carrier to interference ratio C/I. For an omnidirectional configuration, the frequency reuse factor K can be approximated by:

$$K=\tfrac{1}{3}*(6*C/I)^{(2/\text{gamma})} \quad (1),$$

where gamma is based upon the terrain environment, also known as the path loss exponent. See reference Lee, William C. Y., *Mobile Cellular Telecommunications Systems*, McGraw-Hill Book Company, 1989, pp. 50–59. (This relationship is applicable both to the uplink and the downlink.) In equation (1), co-channel interference I on the downlink is only associated with interference that is generated by base stations, other than the serving base station, transmitting at the same frequency as the serving base station. Conversely, co-channel interference I on the uplink is only associated with interference that is generated by mobile subscriber units, other than the served mobile subscriber unit, transmitting on the given frequency and located in cells allocated with the same given frequency. However, co-channel interference I in equation (1) does not include the additional interference caused by IM products. As a result, interference I in equation (1) must be adjusted to compensate for the effects of IM products in order to achieve the same quality of service without the effects of IM products. Thus, one must increase C/I to compensate for the additional interference caused by IM products.

As an example, if C/I=19.5 dB without the presence of IM products and gamma=3.5, one determines that the frequency reuse factor K=12 from equation (1). However, if the total interference (co-channel interference plus the effects of IM products) is increased by 2 dB as a result of IM products, one determines that the frequency reuse factor is increased to 15.6. In this case, C/I is increased to 21.5 dB to compensate for the effects of IM products. Since cell site fractions cannot be considered in the frequency reuse factor, one must round up the frequency reuse factor to 16. In this example, the size of the channel set is reduced by approximately 24 percent if the effects of IM products are included. The essence of this example is that the effect of IM products reduces the call capacity of a cellular radio system, assuming that the grade of service is maintained. A similar analysis can be applied to a directional configuration by one skilled in the art.

FIG. 3*a* is a flow diagram showing the logic for selecting channels for a channel set according to this invention. In step **300**, one constructs a collection of channel sets that reduces the measure of homogeneity. Several algorithms that provide a reduction of homogeneity will be described. Channel sets that have a reduced measure of homogeneity are referred to herein as "modified channel sets." In step **301**, modified channel sets are associated with the base stations according to the antenna configuration and the frequency reuse factor. A representation of the calculated modified channel sets is stored into a memory device for later retrieval. The memory device is located at an entity of the cellular radio system such as the base station or a mobile switching center that is associated with the base station. In step **302**, the cellular radio system determines whether a mobile unit is requesting a call or that there is an incoming call for a mobile subscriber unit. In step **303**, the representation of an appropriate modified channel set is retrieved from memory and a channel number is chosen from the modified channel set. The modified channel set is associated with the antenna sector in which the mobile subscriber unit is located when the call is setup. The channel number is allocated to the call. If, during the call, the cellular radio system determines that a handoff is necessary in step **304**, the cellular radio system retrieves the representation of an appropriate modified channel set and assigns a new channel number from this modified channel set in step **305**, which corresponds to the cell and antenna sector that the mobile subscriber unit has moved to. In such a case, the old channel number is relinquished so that the old channel number can be allocated to a different call. In step **306**, the cellular radio systems determines if the call is released, either by the mobile subscriber unit or by the party that was connected to the given mobile subscriber unit during the call. If the call is released, the previously allocated channel number is relinquished in step **307** so that the channel number can be allocated for a different call.

In step **300** in FIG. 3*a*, an algorithm transforms purely homogeneous sets, such as shown in Tables 1, 2, and 3, into modified channel sets. The purpose of the algorithm, according to this exemplary embodiment of this invention, is to decrease the degree of homogeneity. In general, the less the homogeneity, the greater the reduction of the number of resulting IM products.

FIG. 3*b* shows a block diagram illustrating an apparatus embodiment in accordance with the present invention. Channel processor **350** constructs modified channel sets from purely homogeneous channel sets in accordance with the call flow shown in FIG. 3*a*. Channel processor **350** can be located at the mobile switching center or base station. Alternatively, channel processor **350** can be separate from the cellular radio system so that calculations are determined at a remote location. The results, as determined by channel processor **350**, are stored in memory **351**. Memory **351** can

be situated at either the mobile switching center or the base station. Assignment processor **352** appropriately selects a channel number from memory **351** in order to set up a call or to handoff a call. Assignment processor **352** instructs transmitter/receiver **353** to tune to the associated radio frequency. Assignment processor **352** can be situated either at the mobile switching center or at the base station. Transmitter/receiver **353** is located at the base station.

FIGS. **4***a*, **4***b*, and **4***c* illustrate one possible algorithm for constructing channel sets in a cellular radio system, which is called the "modified zig-zag" algorithm. This algorithm, combined with the logic shown in FIG. **3***a*, presents an exemplary embodiment of the invention. In step **400** of FIG. **4***a*, it is determined if the number of channel numbers remaining in each of the purely homogenous channel sets is at least 12. (Initially, the number of remaining channel numbers is equal to all of the channel numbers. Also, each channel set has the same number of channel numbers.) If so, step **402** partitions 12 channel numbers of each purely homogeneous channel set into a group for the corresponding purely homogeneous channel set. These channel numbers are removed from subsequent processing if step **400** is repeated. If step **400** determines that there are less than 12 channel numbers remaining in each purely homogeneous channel set, step **401** appends the necessary number of unused channel numbers so that groups can be formed in step **402**. An equivalent alternative to appending is to truncate partitioning. Step **403** transforms the groups of the purely homogeneous channel sets into corresponding groups- of the modified channel set. Step **403** corresponds to FIG. **4***b*, which is described shortly. In step **404**, if any channel number remains in each purely homogeneous channel set, step **400** is repeated. Otherwise, the process is completed in step **405**.

In FIG. **4***b*, groups **421**, **422**, and **423** represent groups of three purely homogeneous channel sets. Each of the purely homogeneous sets is ordered so that channel numbers have progressively larger values. As an example, one can choose preferably three adjacent purely homogeneous channel sets shown in Tables 1, 2, and 3. The modified channel set is derived by processing the three purely homogeneous sets with the modified zig-zag algorithm. FIG. **4***b* shows a modified group **420**, a first group **421**, a second group **422**, and a third group **423** associated with a modified channel set, a first purely homogeneous channel set, a second purely homogeneous channel set and a third purely homogeneous channel set, respectively. First channel number **436** of modified group **420** is the same as first channel number **424** of first group **421**. Second channel number **437** of modified group **420** is equal to second channel number **425** of second group **422**. Third channel number **438** of modified group **420** is equal to third channel number **426** of first group **421**. Fourth channel number **439** of modified group **420** is equal to fourth channel number **427** of second group **422**. Fifth channel number **440** of modified group **420** is equal to fifth channel number **428** of second group **422**. Sixth channel number **441** of modified group **420** is equal to sixth channel number **429** of third group **423**. Seventh channel number **442** of modified group **420** is equal to seventh channel number **430** of second group **422**. Eighth channel number **443** of modified group **420** is equal to eighth channel number **431** of third group **423**. Ninth channel number **444** of modified group **420** is equal to ninth channel number **432** of third group **423**. Tenth channel number **445** of modified group **420** is equal to tenth channel number **433** of first group **421**. Eleventh channel number **446** of modified group **420** is equal to eleventh channel number **434** of third group **423**. Twelfth channel number **447** of modified group **420** is equal to twelfth channel number **435** of first group **421**. This process is repeated for the remaining groups of the purely homogeneous channel sets.

Applying the modified zig-zag algorithm to the first three purely homogeneous channel sets in Table 1, the number of IM products is greatly reduced. In this example, the first purely homogenous channel set contains channels **1, 22, 43, 64, 85, 106, 127 148, 169, 190, 211, 232, 253,** and **274**; the second purely homogeneous channel set contains channels **2, 23, 44, 65, 86, 107, 128, 149, 170, 191, 212, 233, 254,** and **275**; and the third purely homogeneous channel set contains channels **3, 24, 45, 66, 87, 108, 129, 150, 171, 192, 213, 234, 255,** and **276**. Applying the modified zig-zag algorithm to these purely homogeneous channel sets, the modified channel set contains channels **1, 23, 43, 65, 86, 108, 128, 150, 171, 190, 213, 232, 253,** and **275**. An analysis indicates that the number of occurrences of third-order IM products (having the form 2f.sub.1−f.sub.2) that correspond to each channel number of the modified channel set is 0.26 on average. This can be compared to the case of purely homogeneous channel sets in Tables 1, 2 and 3, in which the number of occurrences is at least 6. When constructing modified channel sets, a number of factors must be considered such as a minimum spacing between channel numbers within the modified channel set, adjacent channel interference, and alternate channel interference. These factors are well known to one skilled in the art.

A second and third modified channel sets are constructed in a similar manner by assigning the remaining channels numbers of channel groups **421**, **422** and **423** to these modified channel sets. The second purely homogenous channel set is associated with first group **421**, the third purely homogeneous channel set is associated with second group **422**, and the first purely homogenous channel set is associated with third group **423** when constructing the second modified channel set. Similarly, when constructing the third modified channel set, the third purely homogenous channel set is associated with first group **421**, the first purely homogeneous channel set is associated with second group **422**, and the second purely homogenous channel set is associated with third group **423**.

FIG. **4***c* shows a flow diagram of the modified zig-zag algorithm and provides an alternative presentation of FIG. **4***b*. Steps **460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470,** and **471** presents the determination of channel numbers **436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446,** and **447**, respectively as shown in FIG. **4***b*. When all 12 channel numbers of the modified group are determined, the routine in FIG. **4***c* is exited in step **472**. The process in FIG. **4***c* corresponds to step **403** in FIG. **4***a*.

The modified zig-zag algorithm is applied to the other purely homogeneous channel sets of Tables 1, 2, and 3 in order to construct a complete collection of modified channel sets. To continue the example, purely homogeneous channel sets Cell 4, Cell 5, and Cell 6 in Table 1 are selected. The process shown in FIG. **4***a* and **4***b* are applied in order to construct two additional modified channel sets. Next, purely homogeneous channels sets Cell 7 (Table 1), Cell 1 (Table 2), and Cell 2 (Table 2) are selected. This process is continued until all purely homogeneous channel sets of Tables 1, 2, and 3 are selected.

Utilizing three purely homogeneous channel sets at a time, the modified zig-zag algorithm is amenable to configurations in which the total number of purely homogeneous channel sets is divisible by three. This algorithm can be applied to other configurations in which the total number

of purely homogenous channel sets is not divisible by three by utilizing a different number of purely homogeneous channel sets. One skilled in the art will recognize how to apply this algorithm in such cases.

FIG. 5 illustrates a flow diagram of an alternative algorithm called the "zig-zag" algorithm. This algorithm can be used when there is an even number of homogeneous channel sets. This algorithm, combined with the logic shown in FIG. 3*a*, presents a second exemplary embodiment of the invention. The zig-zag algorithm is conceptually simpler than the modified zig-zag algorithm; however, the reduction of IM products is not as great as with the modified zig-zag algorithm. A modified channel set is constructed by processing two purely homogeneous channel sets with the zig-zag algorithm. Partitioning into groups is not required as with the modified zig-zag algorithm. As with the modified zig-zag algorithm, the purely homogeneous channel sets are ordered in progressively larger magnitude. The zig-zag algorithm selects channel numbers from first and second purely homogeneous channel sets by progressively incrementing index pointer i. In step **500**, index pointer is set to 1, corresponding to the first channel number. If no channel numbers remain in step **501**, the routine is exited in step **502**. If a channel number remains in the purely homogeneous channel sets as determined by step **501**, step **503** determines that the ith channel number of the modified channel set is equal to the ith channel number of the first purely homogeneous channel set. If step **503** is executed, index pointer i is incremented in step **504**. In step **505**, the ith channel number of the modified channel set is equal to the ith channel number of the second purely homogeneous channel set. Index pointer i is then incremented in step **506**. Step **501** is repeated. Once the first modified channel set is constructed, a second modified channel is constructed by exchanging the roles of the first purely homogeneous channel and the second purely homogenous channel set in steps **503** and **505**. The routine in FIG. 5 is executed a second time.

Both the modified zig-zag algorithm and the zig-zag algorithm are examples of deterministic approaches in constructing modified channel sets. Such approaches construct a modified channel set in a fixed fashion. FIG. 6 illustrates the "randomized" algorithm, which reduces the occurrence of IM products by reducing the degree of homogeneity of the modified channel sets as compared to that of purely homogeneous channel sets. This algorithm, in conjunction with the logic shown in FIG. 3*a*, presents a third exemplary embodiment of the invention. In FIG. 6, three modified channel sets are constructed from three purely homogeneous channel sets. The randomized algorithm selects channel numbers from first, second, and third purely homogeneous channel sets by progressively incrementing index pointer i. In step **600**, index pointer is set to 1, corresponding to the first channel number. If step **601** determines that no channel numbers remain in the purely homogeneous channel sets, then the routine is exited in step **602**. If a channel number remains in the homogeneous channel sets as determined by step **601**, step **603** randomly chooses an integer n from 1, 2, and 3. In step **604**, the ith channel number of the first modified channel set is equal to the ith channel number of the nth purely homogeneous channel set. In step **605**, an integer m is randomly chosen from an integer not chosen in step **603**. In the notation shown in step **605**, the integer following the ":" indicates that the specified integer is not considered when randomly choosing an integer. In step **606**, the ith channel number of the second modified channel set is equal to the ith channel number of the mth purely homogenous channel set. In step **607**, an integer p is equal to the integer not chosen in steps **603** and **605**. In step **608**, the ith channel number of the third modified channel set is equal to the ith channel number of the pth purely homogeneous channel set. Index pointer i is incremented in step **609**, and step **601** is then repeated. When this routine has completed, three modified channels have been constructed. In order to construct the next three modify channel sets, this routine is repeated with the next three homogeneous channel sets and so forth.

The quantitative assessment of third-order IM products heretofore includes only the effects of frequency pairs and not frequency triplets. However, the benefits of the present invention apply both to frequency triplets and to frequency pairs. Such benefits can be appreciated by one skilled in the art.

If a channel set contains a plurality of purely homogenous channel sets, such as the B frequency band of the 850 MHz cellular spectrum, the algorithms discussed heretofore can be applied separately to each purely homogeneous channel set.

Cellular radio service is currently applicable to several frequency spectra centered around 850 MHz and around 1.8 GHz and to different radio technologies such as Advanced Mobile Phone Service (AMPS), Time Division Multiple Access (TDMA), Groupe Special Mobile (GSM). One skilled in the art will recognize how to apply these algorithms to different radio spectra and radio technologies. Moreover, these algorithms are applicable to future allocated radio spectra in which the frequency reuse factor is greater than 1.

Other algorithms that reduce the degree of homogeneity can be devised by one skilled in the art. Moreover, the approaches described heretofore are applicable to the 850 MHz cellular frequency spectrum, the PCS frequency spectrum, the GSM frequency spectrum, ETACS/TACS frequency spectrum, the PDC frequency spectrum, and other frequency spectra that may be allocated in the future for cellular radio systems. Moreover, current art assigns channel numbers to channel sets strictly using purely homogeneous channel sets. Any deviation from this practice would fall under the claims of this invention.

It is to be understood that the above-described embodiment is merely an illustrative principle of the invention and that many variations may be devised by those skilled in the art without departing from the scope of the invention. It is, therefore, intended that such variations be included with the scope of the claims.

What is claimed:

1. A method for determining cellular radio channel assignments to minimize interference due to intermodulation products comprising the steps of:

choosing at least a first and second purely homogeneous channel set associated with a transmission site wherein each channel set contains channel numbers arranged in progressively larger amplitude order;

generating a table in which said at least first and second purely homogeneous channel sets define respective first and second columns with each column containing channel numbers arranged in progressively larger amplitude order; and

constructing a modified channel set from channels contained in said first and second columns by selecting only one channel from each row of said table.

2. The method according to claim 1 wherein said choosing step comprises choosing first, second and third purely homogeneous channel sets, said generating step comprising generating a table with first, second and third respective

columns, and said constructing step constructing a modified channel set based on said first, second and third columns by selecting only one channel from each row of said table and limiting the number of consecutive selections from a single column to less than three.

3. The method according to claim 1 further comprising the step of storing the constructed, modified channel set in which each stored channel is stored in order by the row from which it was selected to define channel assignments.

4. The method according to claim 3 further comprising the step of determining the channel number to be used based on the stored channel set, the determining step determining the channel number to be used based on the first stored channel that is available for use.

5. The method according to claim 2 further comprising the step of storing the constructed, modified channel set in which each stored channel is stored in order by the row from which it was selected to define channel assignments.

6. The method according to claim 5 further comprising the step of determining the channel number to be used based on the stored channel set, the determining step determining the channel number to be used based on the first stored channel that is available for use.

7. An apparatus that determines cellular radio channel assignments to minimize interference due to intermodulation products comprising:

means for choosing at least a first and second purely homogeneous channel set associated with a transmission site wherein each set contains channel numbers arranged in progressively larger amplitude order;

means for generating a table in which said at least first and second purely homogeneous channel sets define respective first and second columns with each column containing channel numbers arranged in progressively larger amplitude order; and

means for constructing a modified channel set from channels contained in said first and second columns by selecting only one channel from each row of said table.

8. The apparatus according to claim 7 wherein said choosing means chooses first, second and third purely homogeneous channel sets, said generating means generates a table with first, second and third respective columns, and said constructing means constructs a modified channel set based on said first, second and third columns by selecting only one channel from each row of said table and limiting the number of consecutive selections from a single column to less than three.

9. The apparatus according to claim 7 further comprising means of storing the constructed, modified channel set in which each stored channel is stored in order by the row from which it was selected to define channel assignments.

10. The apparatus according to claim 9 further comprising means for determining the channel number to be used based on the first stored channel that is available for use.

11. The apparatus according to claim 8 further comprising means for storing the constructed, modified channel set in which each stored channel is stored in order by the row from which it was selected to define channel assignments.

12. The apparatus according to claim 11 further comprising means for determining the channel number to be used based on the stored channel set and the first stored channel that is available for use in the order stored.

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